Neutrino Beam Commissioning

Adam Para
Fermilab

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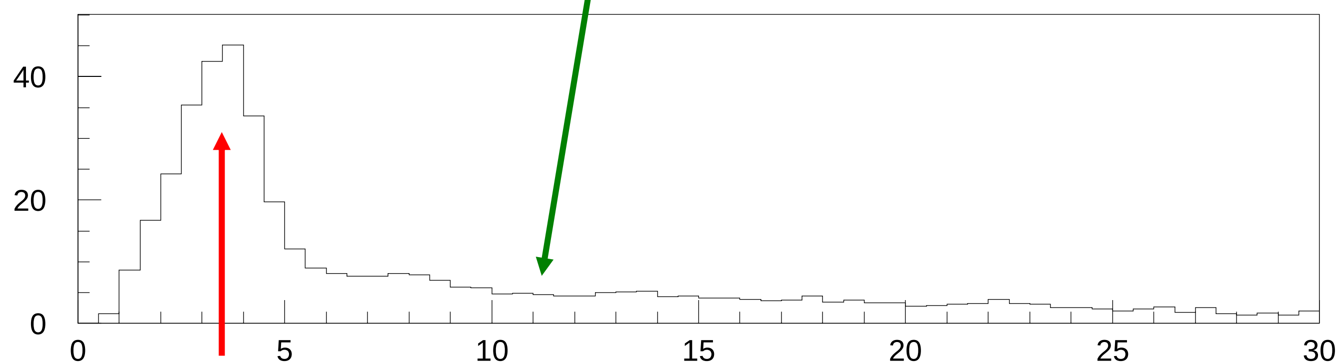
Neutrino Beam Commissioning

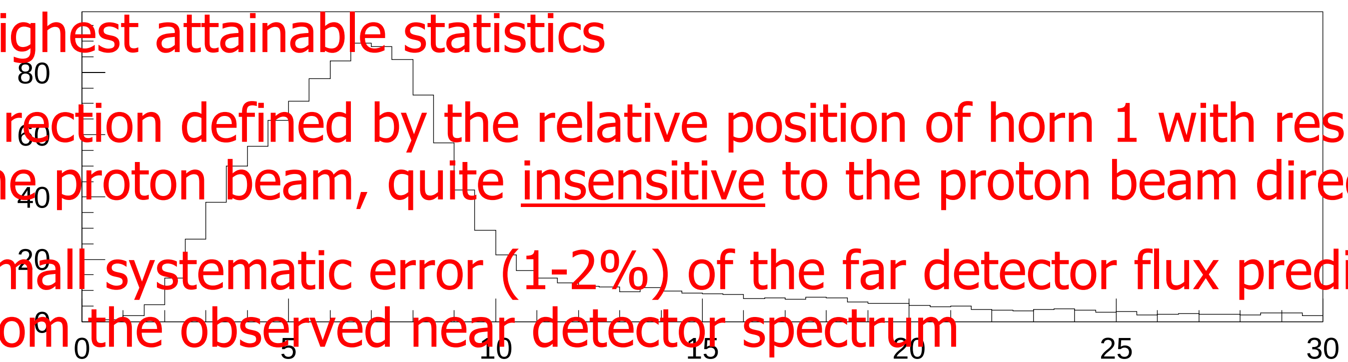
- Three related subjects:
  - Beam commissioning
  - Diagnostics in case of beam malfunctioning
  - Neutrino beam re-commissioning after a replacement of beam elements
- Objective:
  - Certify that the beam elements are positioned/function within prescribed tolerances
  - Identify possible misplacements/malfunctioning
  - Collect auxiliary data (if any, to be defined) to validate our understanding of the neutrino beam

Neutrino Beam Components

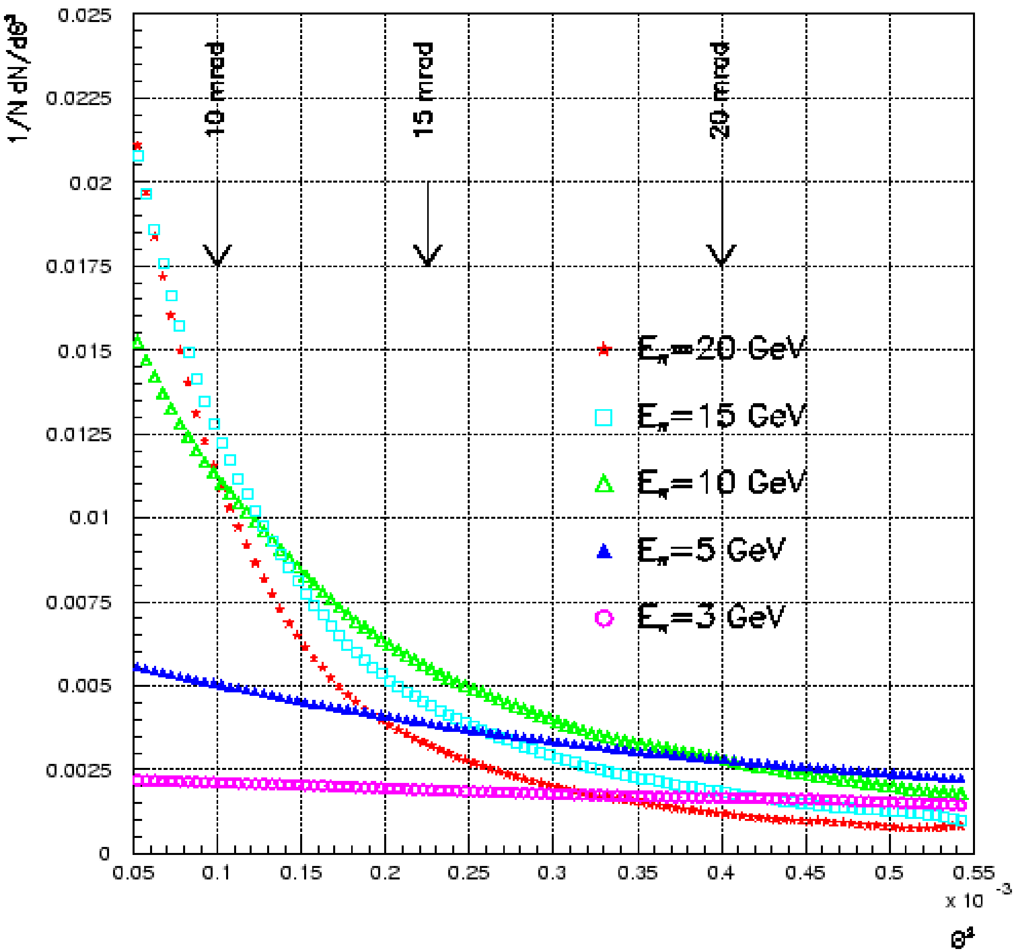
- Pions going through the neck of horn 1, bare target beam:
  - direction defined by the proton beam direction
  - Flux error dominated by pion production uncertainty



- **Pions focused by the horns**
  - Highest attainable statistics
  - direction defined by the relative position of horn 1 with respect to the proton beam, quite <u>insensitive</u> to the proton beam direction
  - Small systematic error (1-2%) of the far detector flux prediction from the observed near detector spectrum



Two-body decay: flux vs angle

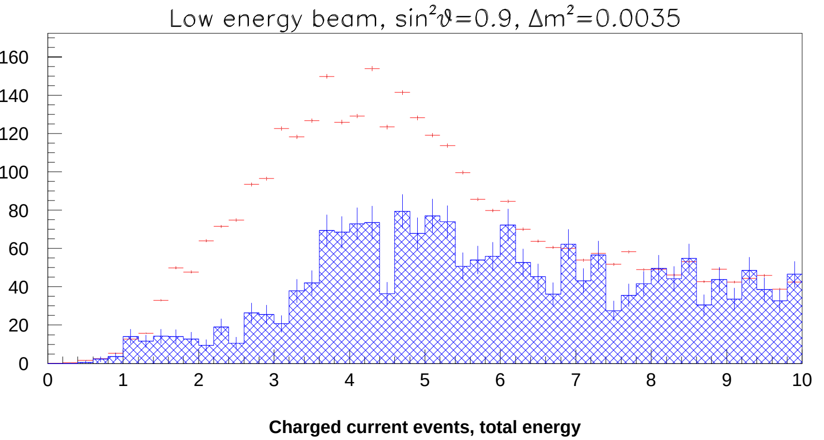


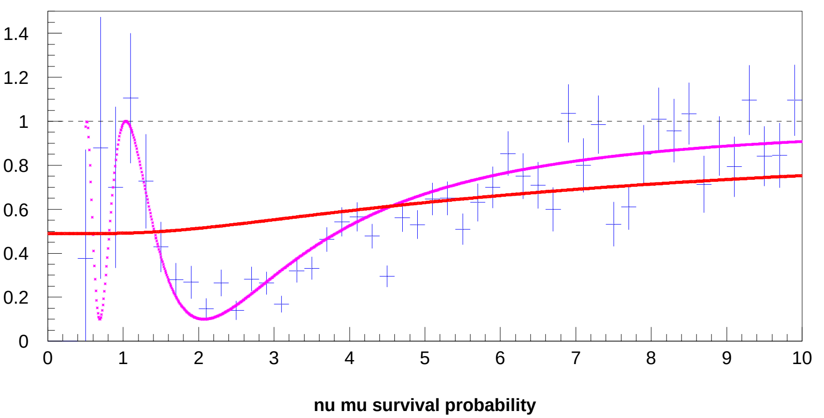
$$Flux = \left(\frac{2\gamma}{1+\gamma^2\theta^2}\right)^2 \frac{A}{4\pi z^2}$$

A sensible goal:
ΔFlux/Flux<0.02

E_ν	E_π	γ	Θ(mrad)
2	5	35	2.8
5	11.6	81.4	1.3
10	23.2	162	0.6
20	46.4	314	0.3

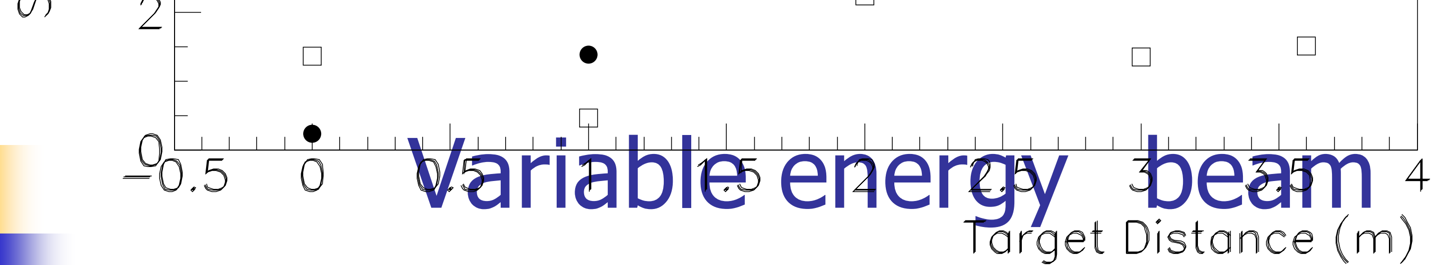
Measure the disappearance curve: over what energy range?

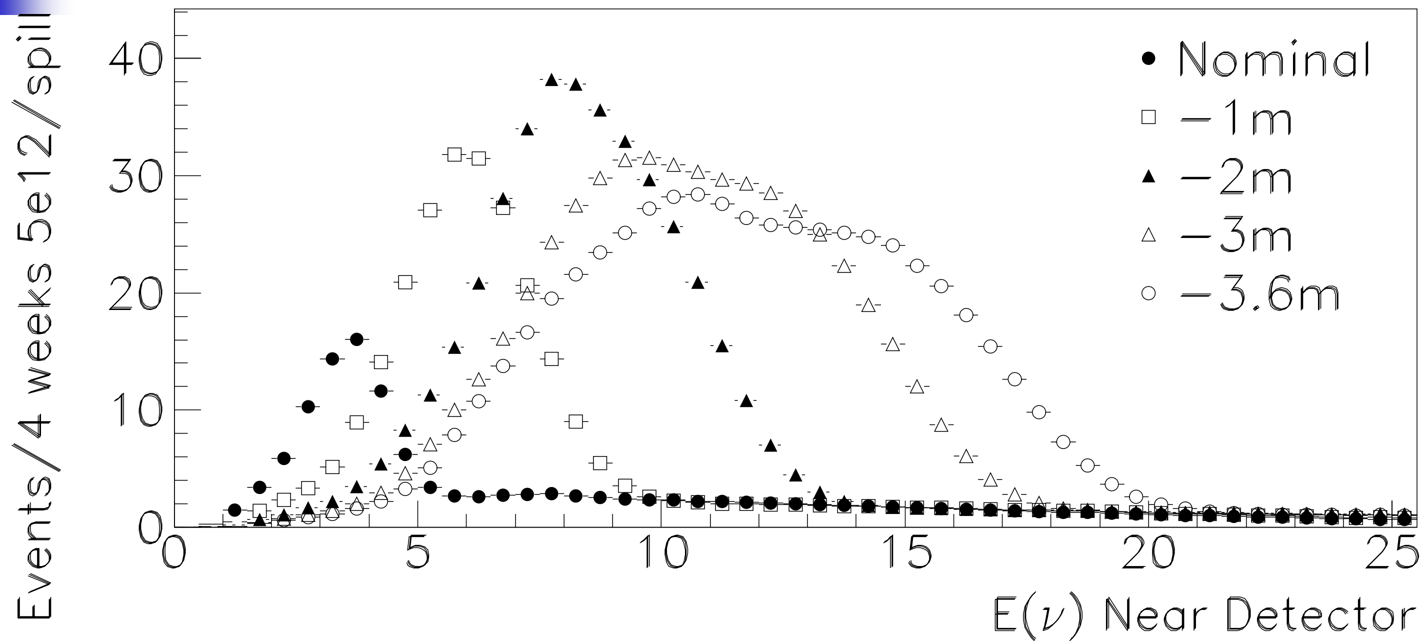




- Observed energy distribution of ν_μ CC interactions provide a measure of the ν_μ survival probability as a function of E_ν
- Low Dm^2 reach limited by the low energy neutrino flux
- Upper limit of interesting energy depends on physics
- For an optimal measurement cover the desired energy range with variable energy beam:
  - Minimize systematic errors
  - Minimize statistical error
  - Provide systematic check by measuring the disappearance probability at the leading/falling edge of the energy spectrum

Variable energy beam



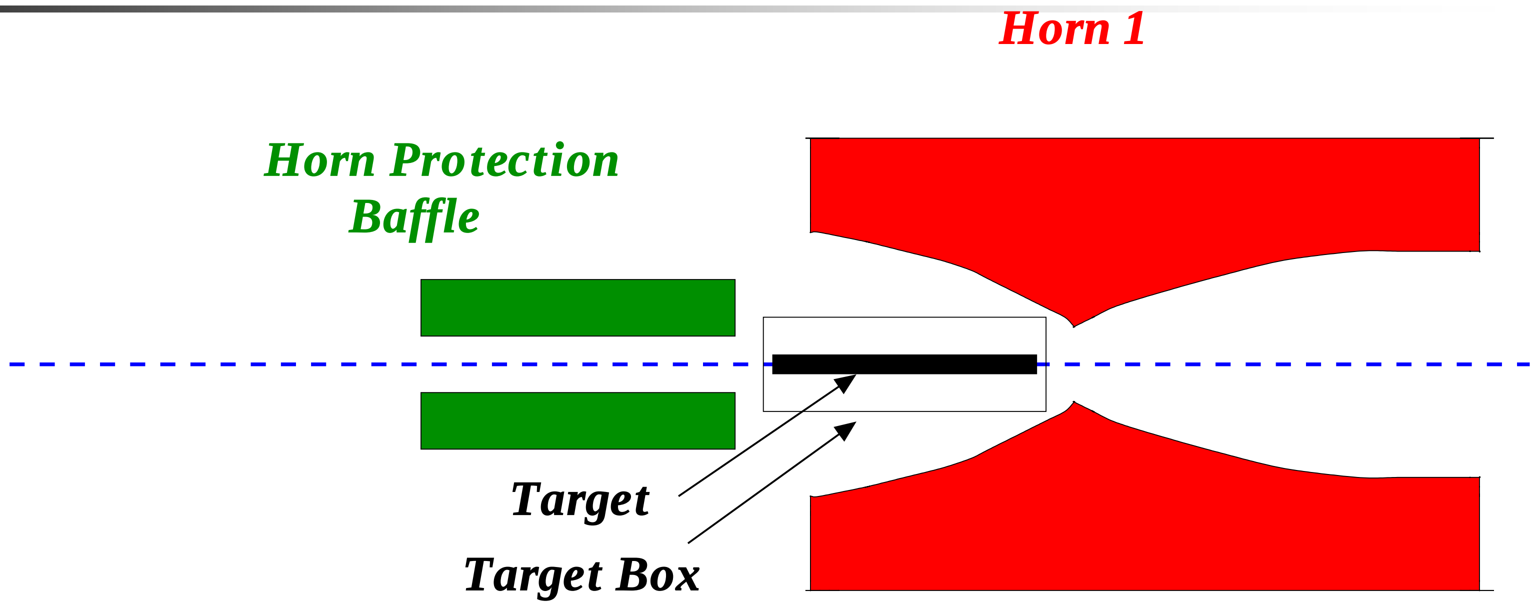


- Horn 1 and 2 at the nominal (Low Energy) positions
- Target retracted by x meters from the nominal position

  - Peak energy (low systematic error) moves to higher energies
  - Event rate in the near/far detectors grows

?? What is a desired? sufficient? range of energies

Neutrino beam elements



Also:

- Horn 2 (to be commissioned)
- Decay pipe (nothing can be done)

Why discuss now?

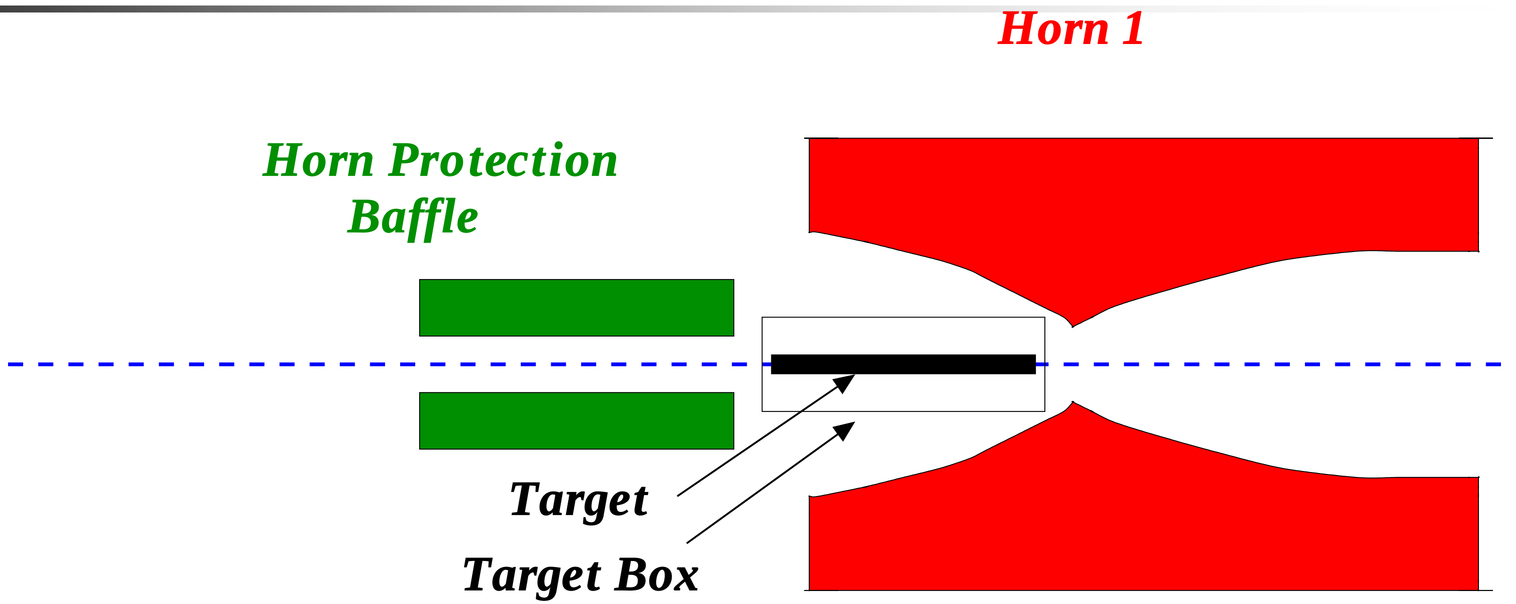
Need to finalize design (baffle/target) and to design the support structures:

•Movement capabilities

•Desired ranges

•Required positioning precision

Neutrino beam elements: functions/sensitivity I



Horn(s):

- Focus the pion beam, define the neutrino beam direction ➔
  - Position with respect to the proton beam/angle (need studies for the low energy beam case)
  - Position with respect to the horn (~0.5 mm)

Neutrino beam elements: functions/sensitivity II

Baffle:

- Protect the inner conductor of the horn, cooling lines of the target (decay pipe window ??) →
  - Position with respect to the horn (~0.5 mm)

Baffle issues (Brajesh):

- Proton beam scraping inside the baffle produces high(er) energy beam component which induces systematic error on the far detector flux prediction
  - Make the baffle opening as large as it is consistent with its protective functions
  - Move the baffle as far from the horn as possible (reduce the systematics by a factor of two)
  - Affect only high energy part of the spectrum, above the 'peak' → not very important if we cover the interesting energy range with the variable energy beams

Neutrino beam elements: functions/sensitivity III

Proton beam/target:

- Produce pions to be focused by the horns →
  - Target size (6.2x15 mm) >> proton beam size (1 mm)
  - Average production point (defined by the proton beam position) needs to be aligned with the center of the horn(s) (~ 0.5 mm ??)
  - Target position/angle not very critical, as long as protons do not miss it (~ 1 mm?)

Proton beam direction myth

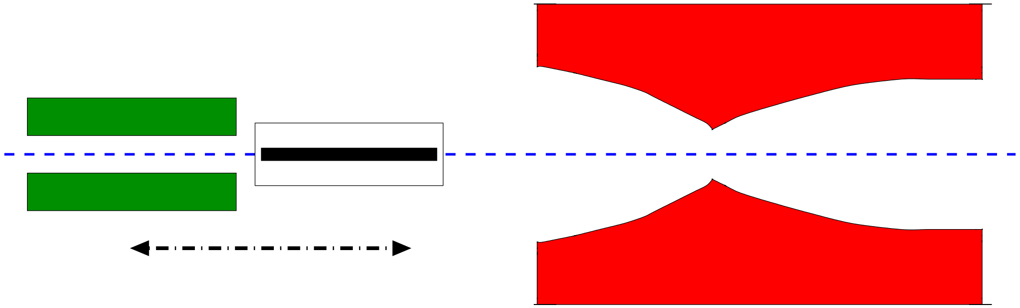
How well do we have to measure absolute proton beam direction?

How large the proton beam angle is geometrically(never mind physically) possible??

- Upstream baffle opening 18 mm, downstream baffle5 mm, distance 45 meters → maximal geometrical angle is 0.023/45 = 0.5 mrad (no beam position)
- Beam Position Monitors/Multiwire chambers spaced by 12 meters, precision <0.5 mm (in absolute space) → precision better than 50 microradians

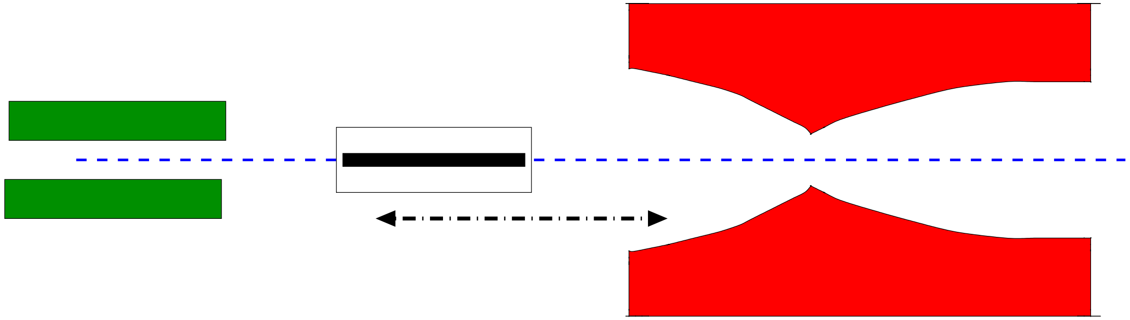
All what is required is to center the horns and the target on the actual proton beam direction.

Moving the target/baffle (along the beam)



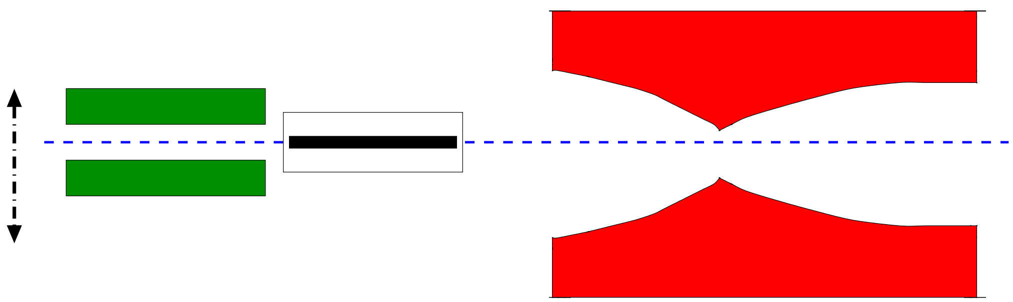
What is the desired range of target movement?

Couple?decouple? motion of the target and the baffle?



Moving the target (transverse to the beam)

Why? To scan the focusing system.. Any useful information to be had? Studies in progress.. (Mark Messier/others)

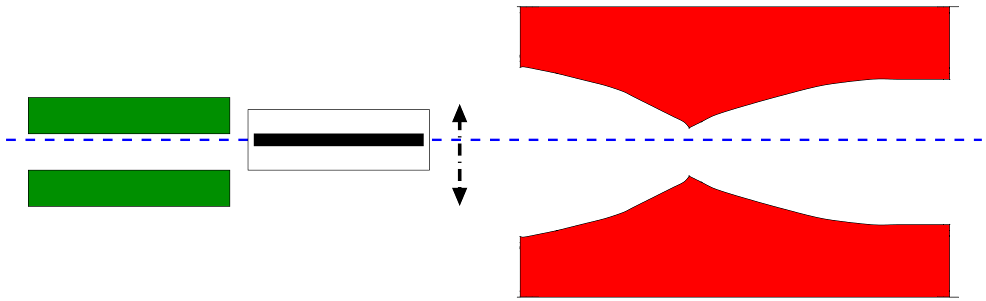


Baffle/target coupled:

- horn in danger at high intensities

Baffle/target mounted separately:

- Maximal flexibility



Alignment of the neutrino beam devices

- Beam position monitors/multiwires
- Baffle
- Target
- Horn 1 and 2

Will be positioned/surveyed with the accuracy ~ 0.5 mm (in absolute reference system). This is <u>more than adequate</u> for the oscillation experiment, especially with the low energy beam.

The purpose of the 'commissioning' is to verify the survey information with the help of the beam-related data.

Best done without movement of the elements in question.

Beyond the baseline: horn fiducials

Motivation:

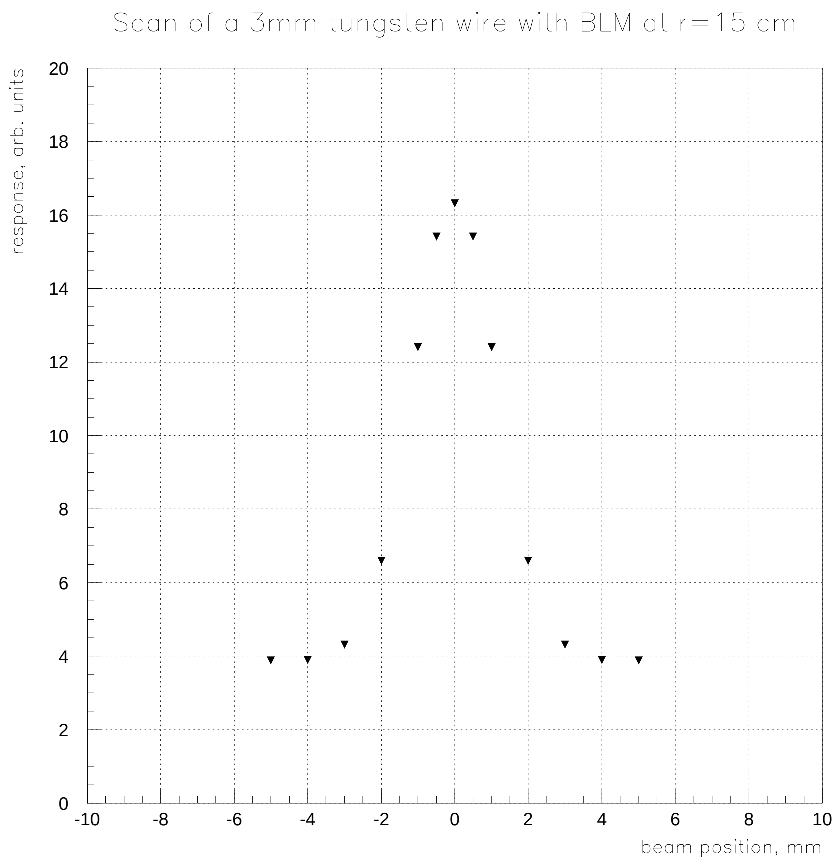
Provide a method of verifying the horn alignment with respect of the proton beam:

- At the beam commissioning phase – cross check of the survey
- During the data taking – diagnostics in case beam conditions change
- After a possible horn replacement

Method:

- A pair of tungsten wired attached to the end of the horn
- Beam Loss Monitor located ~ 1 m behind the horn
- Move the proton beam across the wires and measye the signal of the BLM

Locating the horn(s) position



- Comfortable signal/noise ratio (expected)
- Expected precision of 100-200 microns possible (limited by the knowledge of the position of the wires with respect to the horn
- Can be done at full or reduced proton intensity
- Target needs to be out of the way

Neutrino beam pre-commissioning

Assume:

- Proton beam extracted from the Main Injector, transported to the Target cave
- Beam Position Detectors functional, BPM's calibrated against multiwire chambers
- Near detector functional and calibrated, reconstruction program debugged and understood
- Muon detectors commissioned and calibrated
- Horns installed and surveyed
- Baffle and target installed, surveyed, remote motion mechanism calibrated
- Horns functional, pulsed, magnetic field measured

Neutrino beam commissioning I
Scenario A: Baffle independent

Low intensity proton beam ($\sim 10 \times 10^{11}$ ppp)

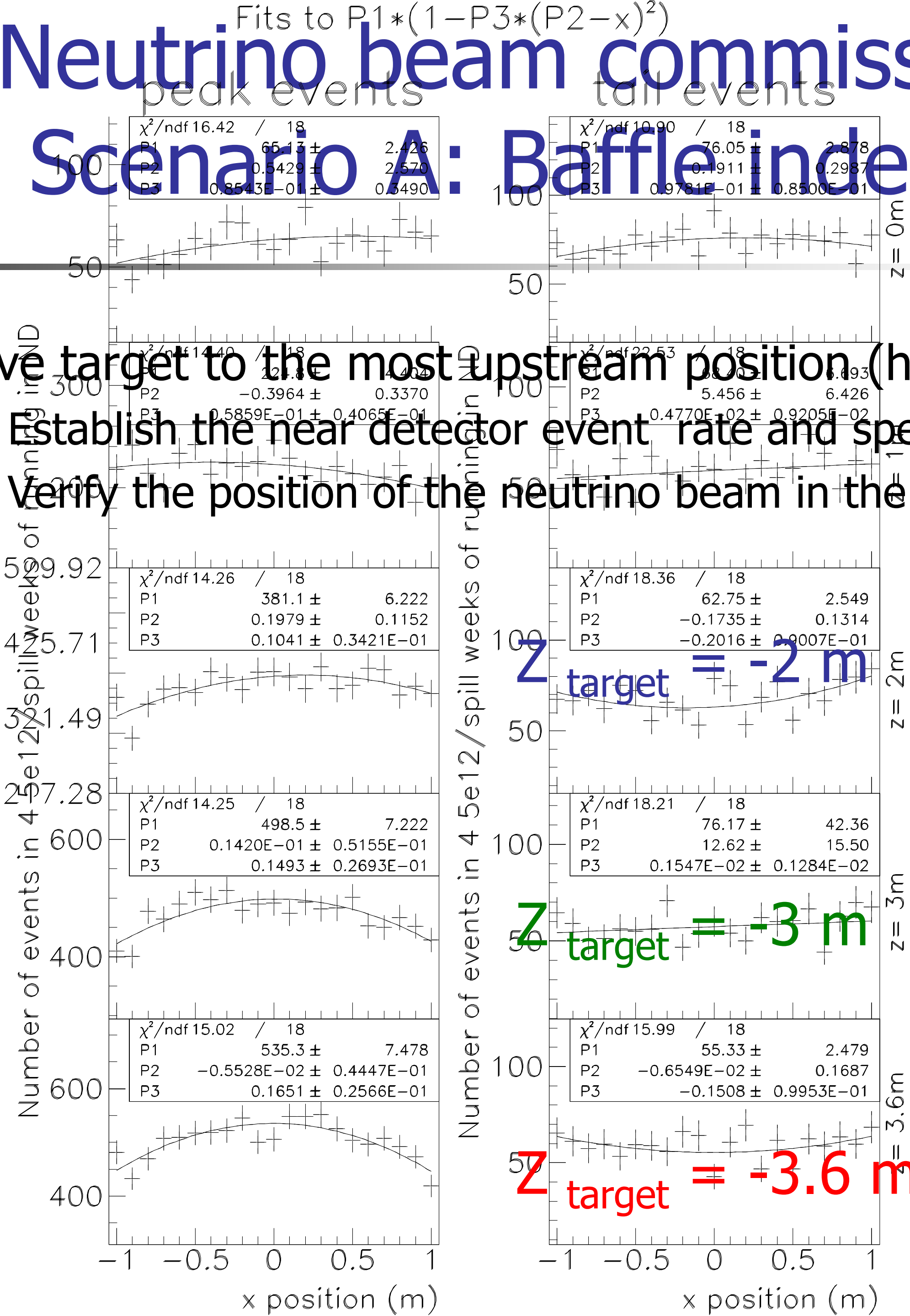
- Verify the alignment of the horn protection baffle: scan the proton beam across the baffle opening
  - Use a thermocouple mounted on the baffle
  - Use a Beam Loss Monitor located downstream of the baffle
- Check horn pulse timing with respect to the beam

Nominal intensity proton beam (target out)

- Verify position of horn 1 using the fiducial cross-wires
- Verify position of horn 2 using the fiducial cross wires
  - This can be turned around into an independent verification of the proton beam direction, assuming the the horns are positioned correctly
- Install the target. Verify target position by moving the beam across and using the Budal monitor.

Neutrino beam commissioning II
Scenario A: Baffle independent

- Move target to the most upstream position (highest energy)
  - Establish the near detector event rate and spectrum (1-2 days)
  - Verify the position of the neutrino beam in the near detector



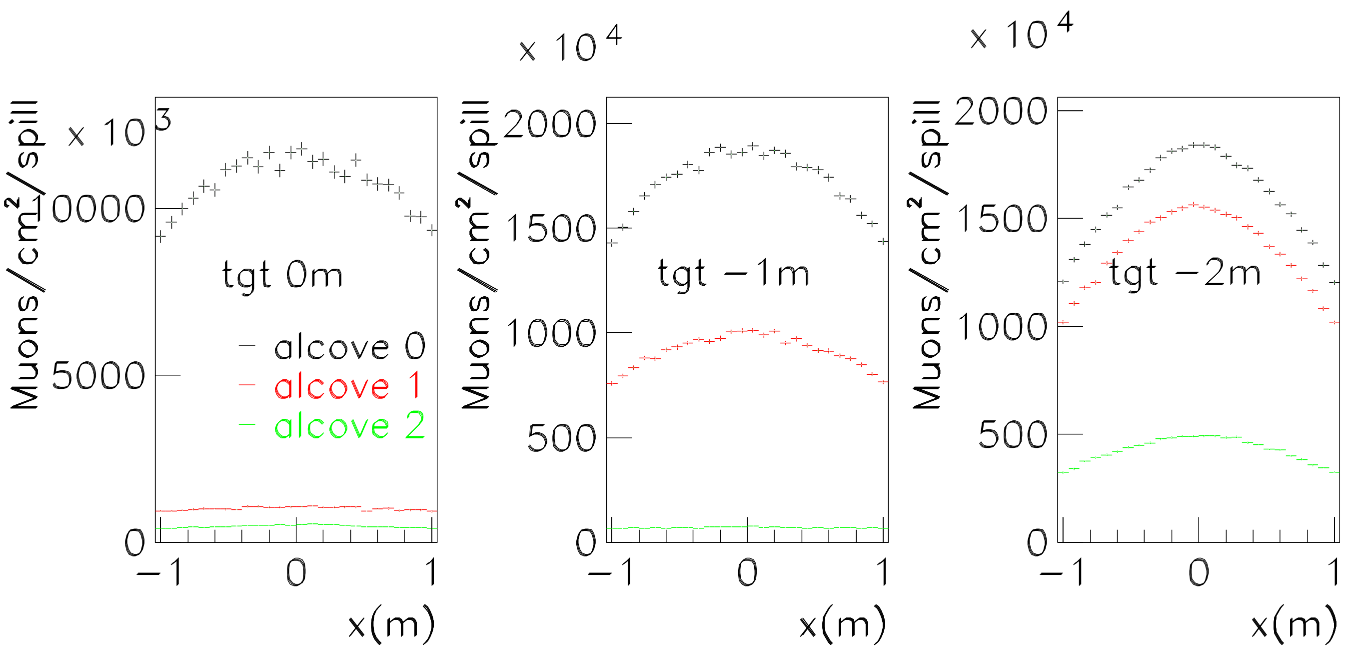
Z_{target} = -2 m

Z_{target} = -3 m

Z_{target} = -3.6 m

Neutrino beam commissioning III Scenario A: Baffle independent

- Move target (in steps of 50 cm) towards the nominal (low energy) position
  - Measure muon spatial distributions in alcoves 0,1 and 2 (~ several minutes per position)
  - Repeat the scan several times to check reproducibility/stability



Neutrino beam commissioning IV
Scenario A: Baffle independent

- Collect any special conditions auxiliary data sets (if any shown to be useful)

Start taking data for oscillations

Neutrino beam commissioning I Scenario B: Baffle/target coupled

Low intensity proton beam (~10×10^{11} ppp) target/baffle out of the beam

- Check horn pulse timing with respect to the beam
- Verify position of horn 1 using the fiducial cross-wires
- Verify position of horn 2 using the fiducial cross wires
  - This can be turned around into an independent verification of the proton beam direction, assuming the the horns are positioned correctly
- Install the target/baffle.
- Verify target position by moving the beam across and using the Budal monitor.
- Verify the baffle position using thermocouples

Switch to the nominal beam intensity, proceed as in scenario A